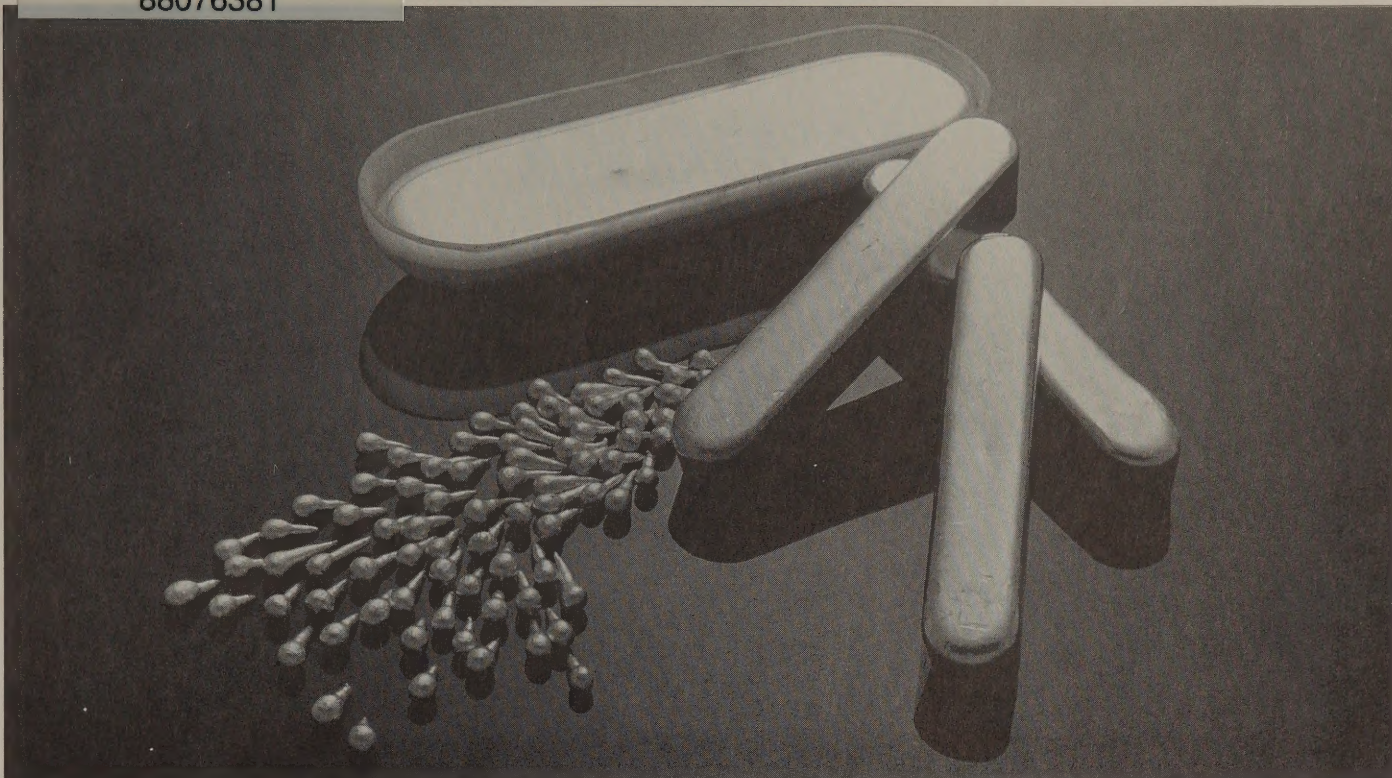
ANNUAL REPORT



INDIUM

By Stephen M. Jasinski

1990

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

INDIUM

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DEPARTMENT
OF THE
INTERIOR

Manuel Lujan, Jr.
Secretary

BUREAU
OF
MINES

T S Ary
Director

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COVER PHOTO:
High-purity (99.99999%) indium for specialty applications, shown in bars, shot, and quartz boat. (Photo is courtesy of Arconium Specialty Alloys.)

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INDIUM

By Stephen M. Jasinski

Mr. Jasinski, a physical scientist with 4 years of U.S. Bureau of Mines experience, has been the commodity specialist for indium since 1988. Domestic survey data were prepared by Eraina Dixon, mineral data assistant.

Domestic indium production was derived from the upgrading of crude indium metal and residues generated in the refining of zinc and other base metals. Two companies accounted for all refined indium produced in the United States. Domestic production data for 1990 were unavailable. Falconbridge Ltd. began production of indium at its Kidd Creek Mine in Ontario, Canada. The indium was to be sold through Indium Corp. of America, as part of a joint-venture agreement. The main uses of indium were for solder, alloys, coatings, plating, and semiconductor compounds. Domestic consumption grew slightly owing to increased usage in coatings.

DOMESTIC DATA COVERAGE

The two refiners of indium in 1990 chose not to respond to the voluntary survey of indium produced from primary sources. Domestic consumption estimates were based on discussions with the major refiners and consumers and analysis of trade data.

BACKGROUND

Definitions, Grades, and Specifications

Indium is silvery-white in color and has a brilliant metallic luster. It is softer than lead, very ductile and malleable, and has a very low melting point; therefore, it is well suited for use in solders and low-melting alloys. It retains these plastic-like properties to temperatures near absolute zero. Indium can endure considerable deformation through compression and cold-welds easily.

Some physical constants of pure indium are chemical symbol In; atomic number, 49; atomic weight, 114.82; melting point, 156.61° C; boiling point, 2,080° C; and density, 7.31 grams per cubic centimeter at 20° C. Standard grade is 99.97% purity, and high grades are available from 99.99% (4N) to 99.99999% (7N) purity.

Industry Structure

Arconium Specialty Alloys, Providence, RI, and Indium Corp., Utica, NY, the only refiners of indium in the United States, produce indium primarily from imported zinc residues, low-grade indium bullion, and indium scrap. Arconium, Indium Corp., and Johnson Matthey Electronics, Spokane, WA, produce high-purity indium shapes, ingots, and foil. Metalspecialties Inc., Fairfield, CT, intermittently recovers indium from old scrap. New scrap is usually returned to the supplier for reprocessing.

In 1990, Arconium was acquired by Alpha Metals Inc. of New Jersey, a producer of solder and plating materials for electronic uses. Both companies are part of Cookson Group PLC of the United Kingdom. The move was made primarily to consolidate the Cookson sales and distribution departments; little change was expected in the operations at either company.

Because indium is primarily recovered from residues, slags, flue dusts, and intermediate compounds resulting from zinc smelting, world mine production is inferred from the average indium content of zinc ore mined. Canada is the largest producer of zinc in the world; therefore, its mine production is believed to contain the largest quantity of indium.

Historically, most of the world's refining capacity has been in Europe. However, recently, most capacity has increased in Asia and North America because new refineries have opened in Canada and Japan in the past several years.

Geology-Resources

Indium occurs predominantly in solid solution in sphalerite, an ore of zinc, but it has been reported in ores of copper, lead, and tin. It does not occur in the native state. The average indium content of the Earth's crust is estimated at 0.1 part per million, about the same as that of silver.[1] The indium content of mined zinc deposits ranges from 0 to 100 parts per million. The highest known indium concentrations are in vein, replacement, and contact metasomatic sulfide deposits, especially those containing tin minerals. The indium contents of these deposits typically range from 100 to 21,000 parts per million. Deposits of this type include those in the Central City district in Colorado, the Argentine Andes, the Cornwall tin district in England, and the Mount Pleasant tin deposit in New Brunswick, Canada.

Because indium is usually recovered as a byproduct of zinc, world indium reserves are based on weighted estimates of the average indium contents of regional zinc ores.

Technology

A variety of methods are employed to recover indium, depending on the source material and indium content. Indium is primarily recovered as a byproduct of zinc processing. Among the more common methods of recovery are leaching the indium-containing material with sulfuric or hydrochloric acid and extracting the crude indium from solution by cementation on aluminum or zinc sheets. Solvent extraction with organic solutions is used to recover indium from dilute solutions. Another method involves the precipitation of indium phosphate selectively from slightly acidic solutions and conversion to oxide by leaching in a strong caustic soda solution, followed by reduction of the oxide to metal.

During the smelting of zinc, the indium concentrates in the zinc-lead bottom metal and is separated from that portion by chlorination under molten salt, forming an indium-rich slag. Indium is recovered from the slag by leaching and cementation on zinc or aluminum sheets. The indium deposits on the sheets as a low-density, sponge-like mass, which breaks away and floats to the surface of the solution. The indium sponge is washed, briquetted, melted, and cast into anodes for electrolytic refining.[2]

Byproducts and Coproducts

Indium is a minor byproduct of processing base metal ores or zinc residues. The value of recovered indium is negligible in relation to the value of zinc production. Coproducts include molybdenum, silver, tin, and tungsten.

Substitutes

In solder and fusible alloys, bismuth can substitute for indium, but only for certain applications because some bismuth-base solders are prone to brittleness. Hafnium can replace silver-indium-cadmium in nuclear control rods.

Economic Factors

Indium, which is classified under Harmonized Code 8112.91.3000 as unwrought, waste and scrap, and powders of indium, was imported free from most favored nations (MFN) and subject to a 25% ad valorem duty from non-MFN.

ANNUAL REVIEW

Legislation and Government Programs

The Defense Logistics Agency, which maintains the National Defense Stockpile, was authorized to procure 2,488 kilograms of indium in 1990, but delayed purchasing indium until a new stockpile acquisition plan is announced in 1991. The inventory on December 31, 1990, was zero, with a goal of 41,990 kilograms.

Consumption and Uses

Domestic consumption was estimated at 30,000 kilograms, a slight increase from that of 1989. The estimated usage pattern was as follows: solders and alloys, 40%; coatings, 35%; electronic and semiconductor uses, 15%; and research and other, 10%.

Indium was available in various forms, such as ingot, foil, shot, ribbon, wire, and powder. Standard-grade indium was generally used in solders, chemical compounds, plating solutions, and fusible alloys. High-purity indium was used for semiconductors, coatings, and solar cells.

Thin film coatings on glass, which included indium oxide and indium tin oxide (ITO), constituted 35% of total domestic indium usage in 1990. Coatings have been the largest area of growth for indium consumption in the past 5 years. Applications involving thin coatings on glass can be divided into two categories, electrically conductive and infrared reflecting. Electrically conductive coatings, the largest group, were used primarily in liquid crystal displays (LCD) for watches, television screens, portable computer screens, video monitors, and other related display devices.

Aircraft and locomotive windshields used a transparent, electrically conductive ITO film as a defroster or defogger. In this application, the electric current heats the film quickly to clear the glass. Indium coatings are more effective than other types of materials, but the use of indium was limited because of its higher cost and limited supply. Several automobile manufacturers have also experimented with indium, but because of the cost and availability factors, most have opted for a zinc-silver oxide coating for quick defrosting windshields. In a similar use, glass doors on commercial refrigerators and freezers are kept free of condensation and frost by a heated thin film of indium oxide.

Another group of films includes visually transparent infrared reflecting coatings on window glass used to control energy losses by reflecting heat inward in winter and outward in summer. For residential windows, the coating is usually applied to a plastic sheet and encased between two panes of glass. This prevents erosion of the coating and reduces the cost of production. Because the expense of refitting a commercial building remains high, other less expensive metals, such as silver, were used as a replacement for indium coatings on commercial windows.

A major use of indium in Europe, and a growing application in the United States, was in the manufacturing of low-pressure sodium vapor street lamps. An indium oxide coating was used on the inside surface of the outer glass cover of the lamp. The indium oxide acts as an infrared reflector, which allows the bulb to operate at a high temperature for improved efficiency. These lights can be recognized by their pink-orange tint.

Electroluminescent (E-L) lamps are thin, flat, flexible light sources used to backlight LCD screens, display panels, and switches for military and civilian applications. An E-L lamp consists of a layer of light-emitting phosphor material on an aluminum foil substrate. A transparent film of ITO, which acts as an electrode, is placed on the phosphor. E-L lighting can penetrate fog, smoke, and haze, making these lights essential in military and commercial aircraft. Tactical military aircraft used E-L lamps for instrument panels and marker lights, and commercial planes used the lamps primarily in safety lighting for aisles and doors.

High-purity indium was an important element for semiconductor materials. Indium phosphide (InP) has become the leading substrate material for optical integrated circuits, fiber optics, laser diodes, optical computers, and signal processing. Indium antimonide and indium arsenide were used in infrared detectors for missile-guidance systems, night-vision instruments, and medical devices.

The use of indium in solar cells has grown during the past several years. Copper-indium-diselenide (CIS) and InP were used to produce cells with some of the highest energy conversion ratios. CIS cells have attained ratios close to 15% for small cells and about 10% for large panels. For the cells to be economically viable, the cost must drop from the current cost of $240 per square meter to $50 per square meter, and the cells must have at least a 30-year lifespan. Gallium can be added to CIS cells to increase the efficiency rating, but it raises the cost of production.

InP cells were used primarily in applications related to space exploration because its resistance to solar radiation is greater than that of gallium arsenide or silicon. An energy conversion factor of 19.1% was achieved in a simulated space environment with an InP cell in 1990.[3] The Japan Space Agency used InP solar cells on the lunar orbiter that it launched in 1990.

A major domestic use for indium has been as an addition to bismuth, cadmium, lead, or tin alloys to lower the melting point. These alloys can be used in

such applications as electrical fuses, fusible links, or as holding material for the grinding of optical glass. Pure indium and several indium alloys will wet glass and were used for glass-to-metal and glass-to-glass seals.

Indium was used as a strengthening agent for lead solder and as the base material for a variety of low-melting-temperature solders. Many indium-base solders have a melting point below 183° C, the melting point of conventional 63% Sn-37% Pb solder used in electronic applications. This makes indium solder useful for components that would be damaged by a high soldering temperature. Indium-base alloys also remain flexible over a greater temperature range than tin-lead solder. Indium solders reduce the possibility of gold scavenging, a problem that occurs when tin-lead solder is used to join gold components. The solder will gradually leach gold from the contact surface, thus weakening or damaging the soldering joint. The Department of Defense approved the use of indium-base solders for certain military equipment in 1990.

Several manufacturers of pressurized water reactors used an alloy consisting of 80% silver, 15% indium, and 5% cadmium for nuclear control rods. The manufacture of these rods declined in the United States in the early 1970's when orders for new nuclear powerplants began to drop. Following the Three Mile Island nuclear accident in 1979, all orders for new nuclear powerplants in the United States ceased, and subsequent consumption has been only for replacement rods, which must be changed every 15 years.

Minor uses of indium included indium-palladium and indium-gold alloys in dentistry, use as a surface lubricant for abrasive compounds, and as an additive to lubricating oil to prevent corrosion. Certain radiation-detection badges used indium foil because low-energy neutrons easily induce radioactivity in indium.

Markets and Prices

Indium demand and production both increased slightly from 1989, and as a result, producers held the price steady. The price of standard-grade, 99.97%-purity indium in the United States gradually decreased from $251 per kilogram ($7.80 per troy ounce) in January to $225 per kilogram ($7.00 per troy ounce) in April, where it remained until the end of the year.

Foreign Trade

The United Kingdom, France, and Belgium were the largest suppliers of indium to the United States in 1990. Data on U.S. exports of indium were not available.

World Review

World refinery production in 1990 was about 118 metric tons. Belgium, Canada, France, Italy, and Japan were the largest producers. World consumption was about 110 tons. Japan and the United States were the largest consumers.

Canada.—Johnson Matthey PLC, United Kingdom, closed its Trail, British Columbia, high-purity metals plant in December. The closing was part of a company restructuring plan. The high-purity metals production was moved to the firm's plants in Spokane, WA, and Vancouver, British Columbia. Johnson Matthey produced high-purity germanium, indium, and other metals in 1990.

Falconbridge Ltd. began production of indium at the Kidd Creek Mine at Timmons, Ontario, in November 1990. The indium was recovered from waste material from the copper-zinc mining operation. The plant had a refinery production capacity of 30 tons per year, but the output was to be adjusted to market conditions. Indium Corp. was to be the sole marketing agent for all indium produced at Kidd Creek. Indium Corp. also planned to upgrade some 99.99% indium from Kidd Creek to 99.999% (5N) and above purity at its Utica, NY, facility.

Canada now has the largest refinery production capacity for indium in the world. Cominco Ltd., which produced indium at Trail, British Columbia, and Falconbridge Ltd., each have the ability to recover up to 30 tons per year.

Japan.—Japan was the largest producer of refined indium in 1990. It produced 48 tons, but only about 25 to 30 tons was estimated to have been derived from Japanese ores. The remainder was derived from upgrading indium-bearing material imported mainly from China and Europe. The leading uses of indium in Japan were for transparent,

TABLE 1

MAJOR WORLD INDIUM PRODUCERS IN 1990

Country	Company
Belgium	Metallurgie Hoboken-Overpelt.
Canada	Cominco Ltd. Falconbridge Ltd. and Indium Corp. of America (joint venture).
China	Several Government metallurgical plants.
France	Metaleurop S.A.
Germany, Federal Republic of	Do.
Italy	Do.
Japan	Nippon Mining Co. Ltd.
Netherlands	Billiton Metaalundustrie NV.
Peru	Empresa Minera del Centro del Peru S.A. (Centromin Peru).
U.S.S.R.	Several Government metallurgical plants.
United Kingdom	Capper Pass Ltd. Mining and Chemical Products Ltd.

TABLE 2

U.S. IMPORTS FOR CONSUMPTION OF INDIUM,[1] BY CLASS AND COUNTRY

Class and country	1988 Quantity (kilograms)	1988 Value (thousands)	1989[2] Quantity (kilograms)	1989[2] Value (thousands)	1990 Quantity (kilograms)	1990 Value (thousands)
Unwrought and waste and scrap:						
Belgium	8,957	$2,855	6,035	$2,544	5,470	$1,146
Bulgaria	17	76	—	—	—	—
Canada	1,685	619	357	105	3,398	788
China	3,378	542	2,444	629	3,390	734
France	4,729	1,576	4,629	1,324	5,675	1,080
Germany, Federal Republic of	439	111	2,931	485	110	33
Hong Kong	—	—	44	12	—	—
Italy	7,490	2,553	2,150	604	3,347	717
Japan	351	416	659	500	380	197
Netherlands	1,771	182	1,109	313	299	80
Peru	1,698	487	914	492	1,927	392
U.S.S.R.	—	—	529	135	—	—
United Kingdom	6,460	3,452	5,012	1,801	6,162	1,387
Total	36,975	[3]12,870	26,813	8,944	30,158	[3]6,555
Wrought:						
China	3	11	—	—	—	—
Japan	79	34	—	—	—	—
United Kingdom	171	401	—	—	—	—
Other	822	69	—	—	—	—
Total	1,075	[3]516	NA	NA	NA	NA

NA Not available.
[1]Because of the implementation of the Harmonized Tariff System in Jan. 1989, import categories for 1989 and 1990 are not necessarily comparable with those in 1988.
[2]Beginning in 1989, only data for unwrought and waste and scrap are available.
[3]Data do not add to total shown because of independent rounding.

Source: Bureau of the Census.

TABLE 3

ESTIMATED WORLD INDIUM REFINERY PRODUCTION AND CAPACITY, 1990

(Metric tons)

	Production	Capacity
North America:		
Canada	15	60
United States	NA	30
Total[1]	15	90
South America:		
Peru	4	6
Europe:		
Belgium	18	25
France	18	20
Germany, Federal Republic of	2	10
Italy	9	12
Netherlands	1	3
U.S.S.R.	5	15
United Kingdom	6	6
Total	59	91
Asia:		
China	13	15
Japan	27	50
Total	40	65
World total[1]	118	252

NA Not available.
[1]Excludes U.S. production.

electrically conductive coatings on glass, E-L lamps, and semiconductors.

Current Research

A lead-indium glass was developed at the Oak Ridge National Laboratory for use in optical mirrors, lenses, prisms, windows, and optical fibers. The glass melts at a low temperature, allowing it to be cast into complex shapes, thus reducing the amount of grinding and polishing required. The high lead content makes the glass resistant to gamma radiation, making it suitable for use in nuclear applications.[4]

OUTLOOK

World reserves and increases in production capacity are sufficient to meet expected demand for indium through the year 2000. Consumption of indium is expected to increase gradually in this period, especially for LCD's, semiconductor materials, and in low-temperature solder for military and commercial electronics. Other uses, such as nuclear control rods, which have a lifespan of 15 years, and fusible alloys should remain steady.

[1]Hurlbut, C. S., Jr., and C. Klein. Manual of Mineralogy. Wiley, 19th ed., 1977, pp. 123–124.
[2]Stevens, L. G., and C. E. T. White. Indium and Bismuth. Ch. in Metals Handbook, ASM Int. 10th ed., v. 2, 1990, p. 750.
[3]Lasers & Optronics. Record Efficiency for Space Solar Cell. V. 9, No. 12, p. 12.
[4]Photonics Spectra. Cast-Glass Optics Minimize Grinding. V. 24, No. 6, June 1990, p. 68.

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